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Characteristics of Stormwater Runoff from Caltrans Facilities

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Abstract: Stormwater runoff from 50 sites representing five different types of the California Department of Transportation (Caltrans) facilities (highways, maintenance stations, park and rides, rest areas, and acceleration/deceleration zones) were monitored by Caltrans during the 2000-01 monitoring season. This study was conducted by Caltrans to generate sufficient water quality data to satisfy permit requirements, research and development, load assessment and modeling, watershed planning, and statistical data quantification. Both flow-paced composite samples collected using automated samplers and single grab samples were collected and analyzed at the sites for a total of 323 station-storm events. Results obtained during the first year characterization study indicate that: (i) analytic data collected during the 2000-01 monitoring tended to have lower concentrations than data collected earlier; (ii) highway sites, in general, have above average concentrations of most constituents; (iii) acceleration/deceleration sites, in general, have above average concentrations of most conventional constituents; (iv) park and rides, rest areas, and maintenance stations, in general, have below average concentrations of most constituents; and (v) the data display a high degree of variability with sample standard deviation typically larger than sample mean.

INTRODUCTION

Caltrans Statewide Stormwater Runoff Characterization Program was initiated principally to satisfy the clean water act requirements as specified by the National Pollution Discharge Elimination System (NPDES). Prior to 1999, each of the twelve Caltrans geographical districts obtained individual, district-specific NPDES permits and developed individual stormwater quality management programs. As of May 1999, Caltrans has refined its statewide stormwater management goals and objectives and obtained a single NPDES stormwater permit. A comprehensive and consistent stormwater management plan (SWMP) was found to be the most effective approach to addressing its activities statewide. As a result, Caltrans developed a unique stormwater management program, which can be used as a model for other transportation agencies to follow (*1*).

The Caltrans Statewide Stormwater Runoff Characterization Study is a multi-year study that has been designed to characterize stormwater runoff from Caltrans facilities such as highways, park and rides, maintenance stations, and rest areas. In addition, the CSSRCS includes an assessment of differences between water quality from areas with decelerating (stop and go) traffic and similar areas with accelerating (free-flowing) traffic. This paper presents the data collected during the first monitoring season (2000-01). In addition, the results obtained from this year's monitoring study will be compared to historical data.

METHODOLOGY

Caltrans water quality characterization and monitoring was carried out using the important steps specified in Figure 1. As shown, the Caltrans water quality characterization can generally be divided into four major areas: storm event monitoring, analytical analysis and data validation, data management, and data analysis and evaluation. These four processes are briefly described below.

Storm Event Monitoring

Storm event monitoring was accomplished by selecting representative sites and storm events. Sites were selected to represent typical Caltrans facilities (highways, park and rides, rest areas, maintenance stations, and acceleration/deceleration zones). The selection of site locations was based on a variety of geographic, climatic/ecologic, and hydrologic conditions that can potentially affect the quality of stormwater discharges. In addition, highway sites were selected based on Annual Average Daily Traffic (AADT). Finally, sites were either selected or rejected as potential monitoring sites based on the ability of the sampling teams to perform the required tasks safely along the roadways, congested urban areas, and isolated rural areas. The locations of monitoring sites are shown in Figure 2. Table 1 summarizes the number of station-storm events monitored for each Caltrans facility type.

To sample an appropriate number of storms, a weather-tracking procedure was established as a guideline for targeting storms producing a minimum of 0.10 inches of rainfall (0.30 inches in Northern California). The amount of rainfall, known as the quantity of precipitation forecasted (QPF), was obtained from the National Weather Service in conjunction with other private weather services up to 72 hours prior to a storm event. Once the probability of a storm event with a targeted QPF was forecasted, monitoring teams were dispatched to the various sites to observe the runoff characteristics and to monitor the automated samplers during the storm event.

Stormwater runoff samples were collected using automated samplers placed at the discharge points downstream of representative drainage areas. A typical Caltrans automated sampler is shown in Figure 3. The monitoring equipment collected flow-weighted composite samples, made flow measurements, and logged rainfall amounts. The data presented in this paper was selected using the criteria for representative discharge as presented in the Caltrans Guidance Manual: Stormwater Monitoring Protocols dated July 2000 (*2*).

Analytical Analysis and Data Validation

Statewide stormwater runoff samples were analyzed for selected conventional constituents, nutrients, and metals (dissolved and total). Analyses were conducted by certified laboratories under the California Environmental Laboratory Accreditation Program (ELAP). Analyses were performed in accordance with the methods and procedures outlined in the project-specific Sampling and Analysis Plan dated October 2000 (*3*). Standard quality assurance and quality control was implemented as stated in the Sampling and Analysis Plan and the Caltrans Guidance Manual. Analytical data was validated using the Caltrans Automated Data Validation (ADV) software issued September 2000 (*4*). The qualification of the data by this program followed the basic guidelines established by the United States Environmental Protection Agency (EPA) for evaluating inorganic and organic analyses.

Data Management

To aid in development of a statewide monitoring database and to maintain consistency, Caltrans has established a data reporting protocol (*5*) in Excel format that is being used by all monitoring teams collecting data. To ensure uniformity, entries into the data fields have been as standardized as possible. Once Excel spreadsheets are reported to Caltrans according to the data reporting protocols, data are imported into an Access database that holds statewide monitoring data. Data are stored in three main tables: sample description, sampling event description, and site description. Sample description consists of information specific to individual samples including lab results, analysis methods and date information. Event description consists of precipitation (start and end time, maximum intensity, antecedent dry period), and runoff (total flow volume, peak flow rate, and start and end time). Site description describes location of the site along with some physical characteristics of the site.

The statewide database was queried to extract an Excel file that contained all the analytical results of highway, maintenance stations, park and rides, rest areas, and acceleration/deceleration monitoring sites. These data were extracted for statistical analysis.

Data Analysis

For the most part, pollutant concentrations in stormwater runoff were reported above the designated reporting limit. Under these conditions, conventional statistical approaches were used to analyze data. For the constituents for which the reported values were below reporting limits, the constituent concentrations were considered to be non-detect. Analytical data containing non-detects were statistically evaluated using the Caltrans Data Analysis Tool (DAT) an Excel add-on program prepared by Caltrans in 2001 (*6*). DAT was developed by evaluating available scientific data analysis methodology and was based on regression on order statistics, which is known as the robust method (*7*).

RESULTS AND DISCUSSION

Results of the Caltrans Statewide Stormwater Runoff Characterization Study conducted during the 2000-01 monitoring season are summarized in Table 2. As shown, a simple statistical analysis was performed to determine the range of values, mean, median and coefficient of variance (CV) for representative conventional parameters (pH, conductivity, TSS, TDS, hardness, DOC, TOC), nutrients (nitrate, TKN, total phosphorus, ortho-phosphate), metals (total and dissolved arsenic, cadmium, chromium, copper, lead, nickel, and zinc). These constituents provide an overview of water quality characteristic for the highway, maintenance, park and rides, rest areas, and acceleration/deceleration zones runoff samples. In addition, these constituents are reported for their primary importance in water quality and for the availability of similar data in the literature for comparison purposes. Previous stormwater monitoring studies conducted by Caltrans in 1997-00 for NPDES compliance and pilot BMP studies included the analysis of additional constituents such as pesticides, fecal and total coliform, and other organic compounds. However, most organic compounds and pesticides were found to be below detection limits (*8*) and were not included in the statewide program.

The results are discussed based on the important findings of composite samples analyzed as part of Caltrans statewide stormwater runoff characterization. In addition, the results obtained from this study are compared with other water quality characterization data obtained from previous Caltrans monitoring activities.

Statewide Stormwater Runoff Characteristics

The mean concentration of conventionals, nutrients, total and dissolved metals for highways, maintenance stations, park and rides, rest areas, acceleration, and deceleration sites are shown in Figures 4 through 7. In general, the figures show the mean concentrations of monitoring results obtained from the 2000-01 winter season are fairly consistent among the monitored facility types. The variations that exist among selected conventional, nutrients, and metals are found to be within expected ranges as will be discussed below. No clear trend in the mean concentrations could be found for any of the facility types, particularly because the variability (coefficient of variation) of the data tends to be large. For instance, it cannot be concluded that the concentrations of metals in highways is higher than other facilities. However, some general trends are apparent. In general, concentrations of most constituents from the highway sites are greater than the combined average for all sites. In general, concentrations of most constituents from the Park and Ride, Maintenance Station, and Rest Area sites were less than the combined average. In general, the mean concentrations of most conventionals for acceleration and deceleration sites were found to be slightly higher than the rest of the facilities. This difference in concentrations is likely attributed to variability in storm conditions, site conditions and sampling randomness, rather than to any fundamental change in runoff water quality (*9*).

Comparison of Statewide Runoff Characteristic with Previous Monitoring Results

Mean concentrations of all constituents obtained from Caltrans highway and maintenance stations as part of the statewide stormwater runoff characterization are compared with previous monitoring results (see Figures 8 and 9). The previous Caltrans monitoring results were obtained from studies related to Caltrans NPDES and structural best management practices (BMPs) pilot projects. The majority of the sites were located in southern California.

As shown in Figures 8 and 9 (explain presentation format), compared to the previous monitoring results, the concentrations of most constituents for the statewide monitoring are lower than the historical concentrations. The lower mean concentrations during 2000-01 monitoring season are perhaps due to selection of more representative sites covering the entire state and storm events. In addition, factors such as urban development, percent paved area, and traffic volume are among parameters that may have contributed to a higher pollutant generation during 1998-99 and 1999-00 monitoring results (*10, 11, 12, 13*). Due to the limited availability of historical data from maintenance stations, park and rides, rest areas, acceleration and decelerations zones, most comparative analyses presented below are focused on highway runoff characteristics.

Concentrations of pollutants in statewide highways stormwater runoff characterization are compared with values reported for other highways monitored previously in Table 3. In general, the pollutant concentrations for nutrients and metals from California highways monitored in 2000-01 are within the range of values reported in the earlier studies (1997-00). However, several conventional pollutants have higher reported means in the earlier studies. In general, site characteristics and environmental conditions play a major role on pollutant concentrations (*9,14*). As mentioned, most previous California monitoring studies were conducted in southern California, where there are more industrial activities, higher traffic, more asphalt surface per drainage area, and less open areas adjacent to the roadways.

In one previous study, Kayhanian et al. (*14*) evaluated the impact of average annual daily traffic (AADT) on highway pollutant concentration. This analysis was conducted using the three years (1997-00) California highway runoff monitoring data. The analysis was performed based on single linear regression and multiple regression using analysis of covariance, stepwise regression analysis, and partial correlation analysis. The conclusions made from these analyses were: (i) in general, the pollutant concentrations in urban highways (AADT>30,000 vehicles per day) are found to be two to ten times higher than those found in non-urban (AADT<30,000 vehicles per day) highways. However, some of the pollutants in non-urban highways were found to be higher than the pollutant concentrations in urban highways, (ii) No linear correlation could be found between highway runoff pollutant event mean concentrations (EMCs) and the AADT including those pollutants that are known to be related to transportation activities (e.g., Pb, Cu, Zn) and (iii) The correlation coefficient in linear regression between pollutant concentrations and AADT is a measure of their linear relationship, not a lack of association or influence. In fact, the AADT was found to have some influence or association with most highway runoff constituent concentration.

SUMMARY

No general conclusion can be made at this time. The following summary is based on the first year of statewide stormwater runoff characterization data presented above:

- Analytic data collected during the 2000-01 monitoring tended to have lower mean concentrations than data collected earlier. These results are likely due to regional differences since most previous monitoring sites were mostly in southern California.
- Highway sites, in general, have above average concentrations of most constituents.
- Acceleration/deceleration sites, in general, have above average concentrations of most conventionals.
- Park and rides, rest areas, and maintenance stations, in general, have below average concentrations of most constituents.

- The data tend to be highly variable. For example, the sample standard deviation of a typical constituent sampled at the 31 highway sites is more than one and one-half times larger than the sample mean.

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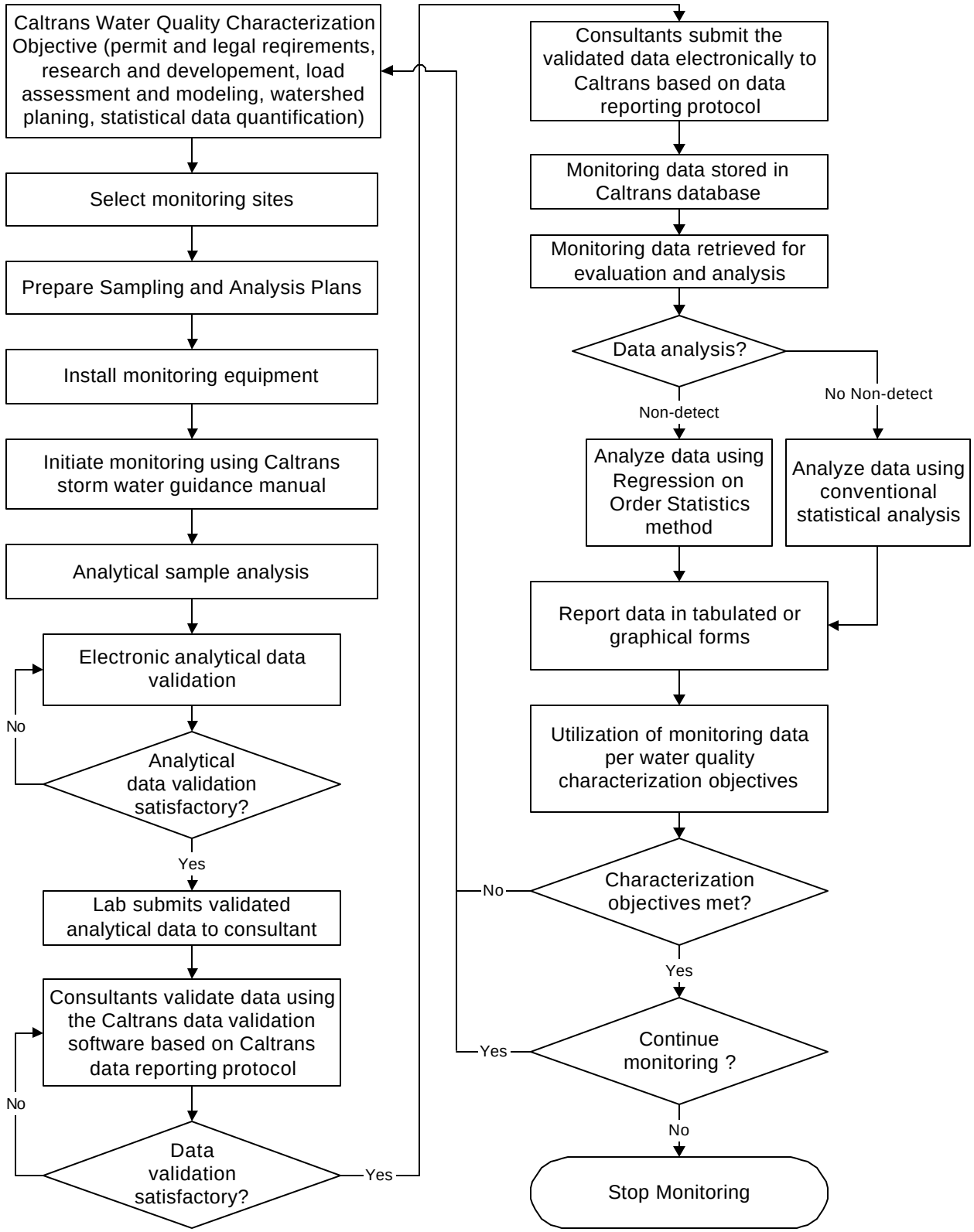

FIGURE 1 Caltrans water quality monitoring process

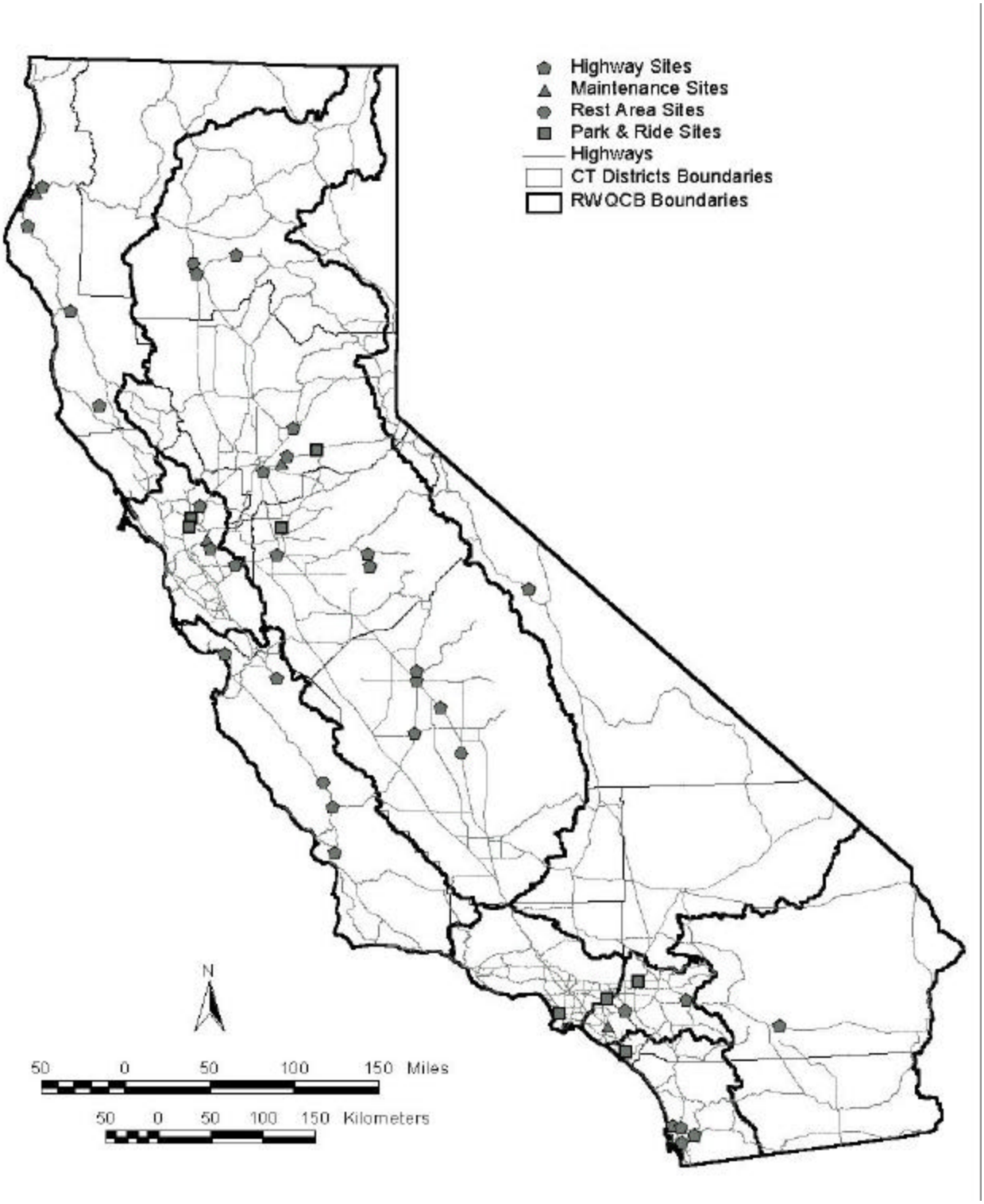

FIGURE 2 Caltrans 2000-01 stormwater runoff characterization monitoring sites

(a) automated monitoring site

(b) close view of automated sampler

FIGURE 3 A typical Caltrans automated stormwater monitoring site

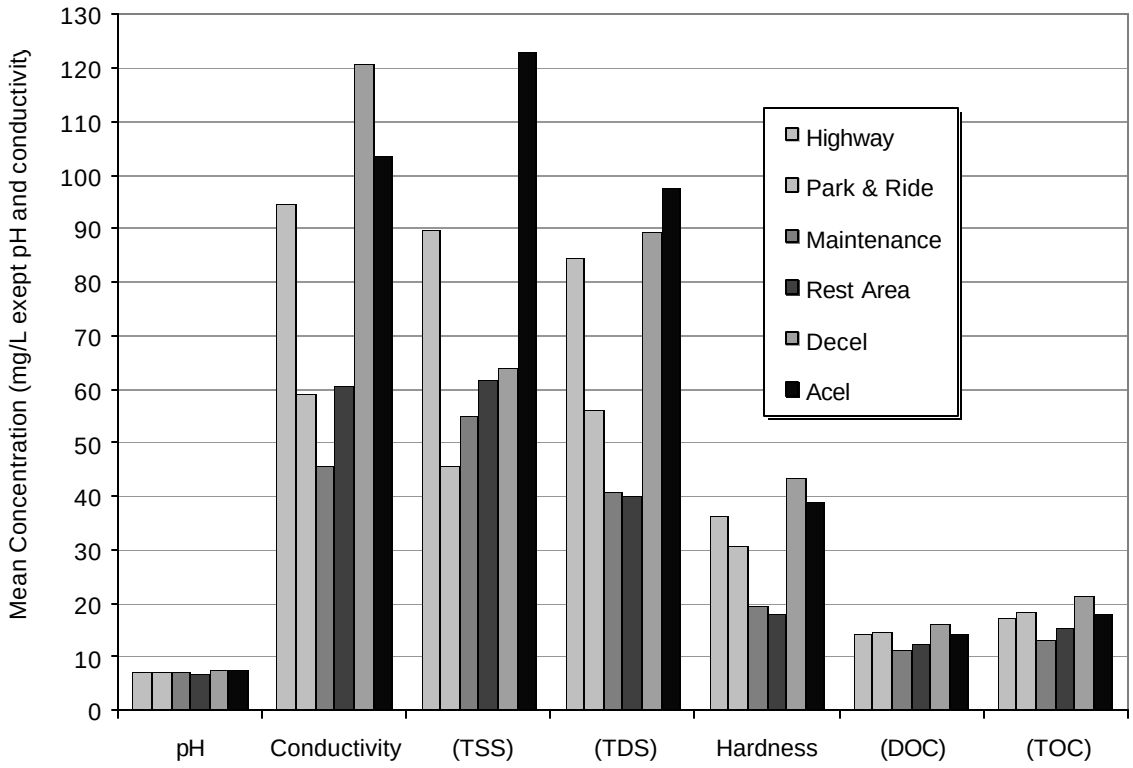

FIGURE 4 Statewide conventional pollutants concentration for different facilities

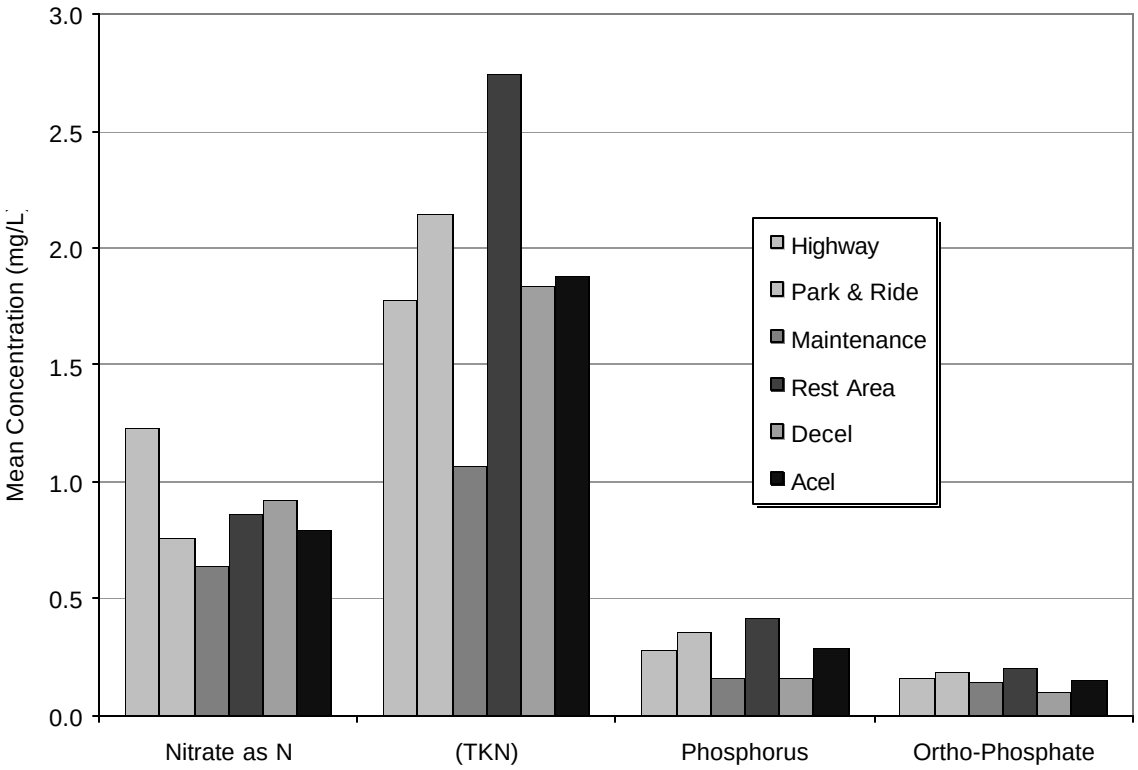

FIGURE 5 Statewide nutrient pollutants concentration for different facilities

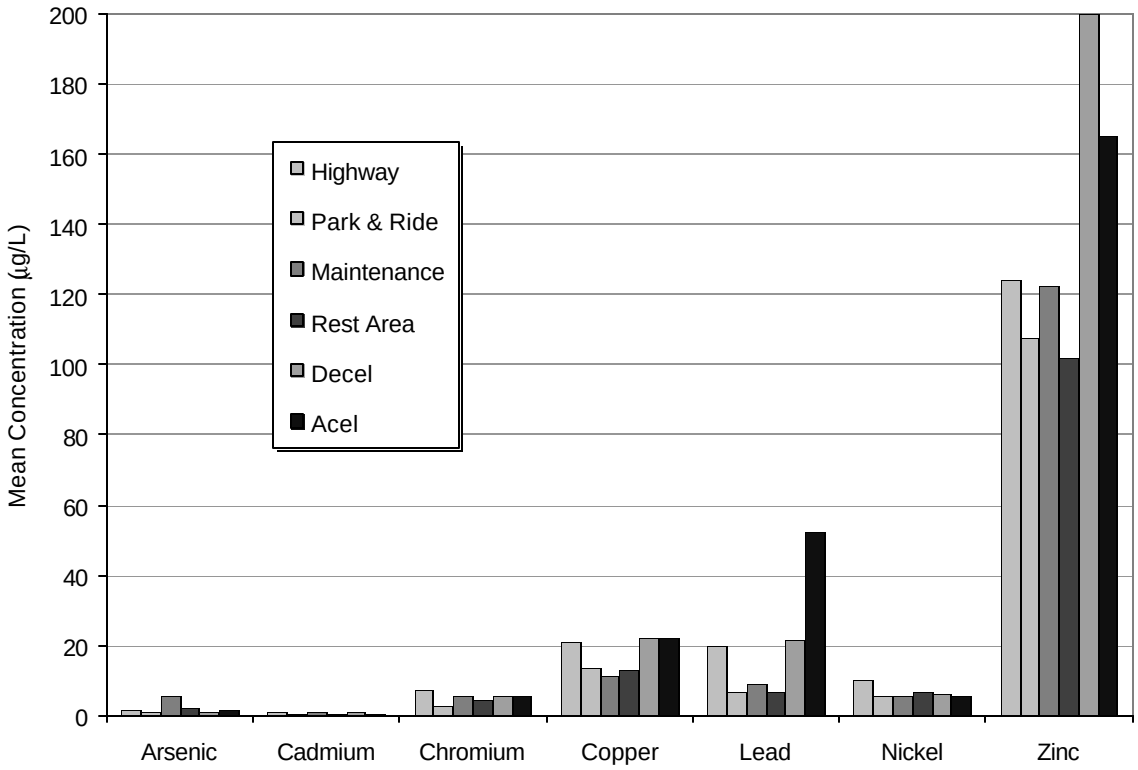

FIGURE 6 Statewide total metal pollutants concentration for different facilities

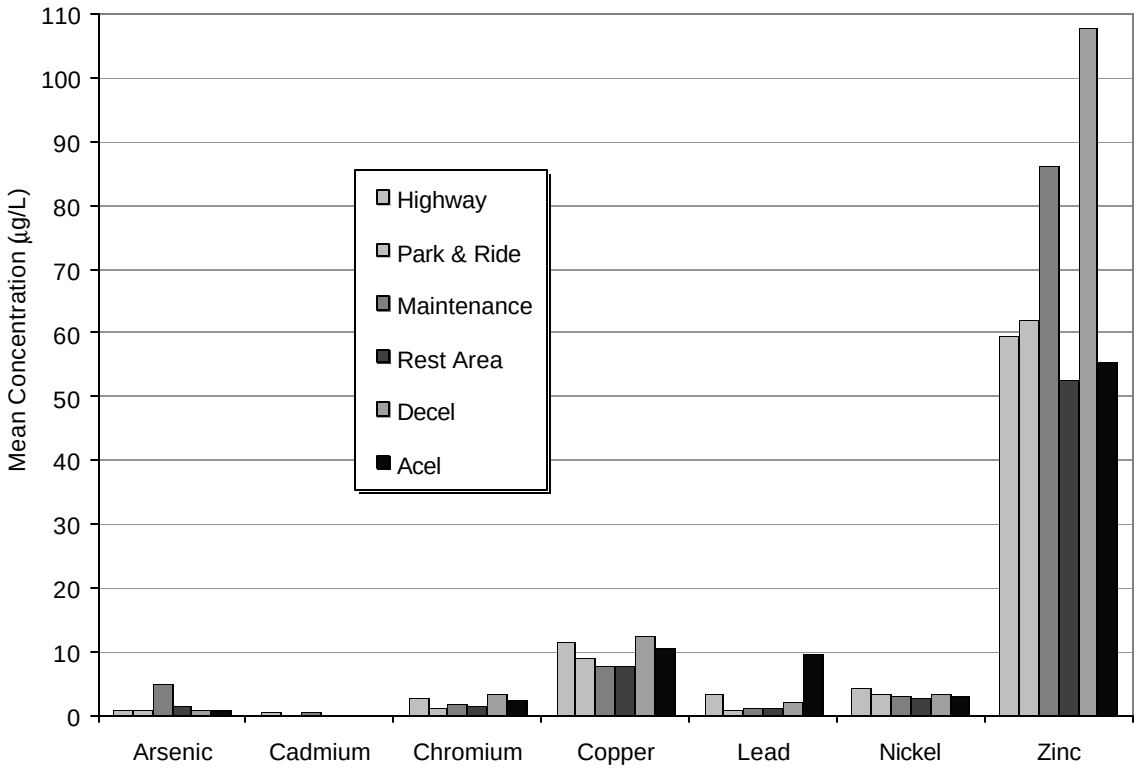

FIGURE 7 Statewide dissolved metal pollutants concentration for different facilities

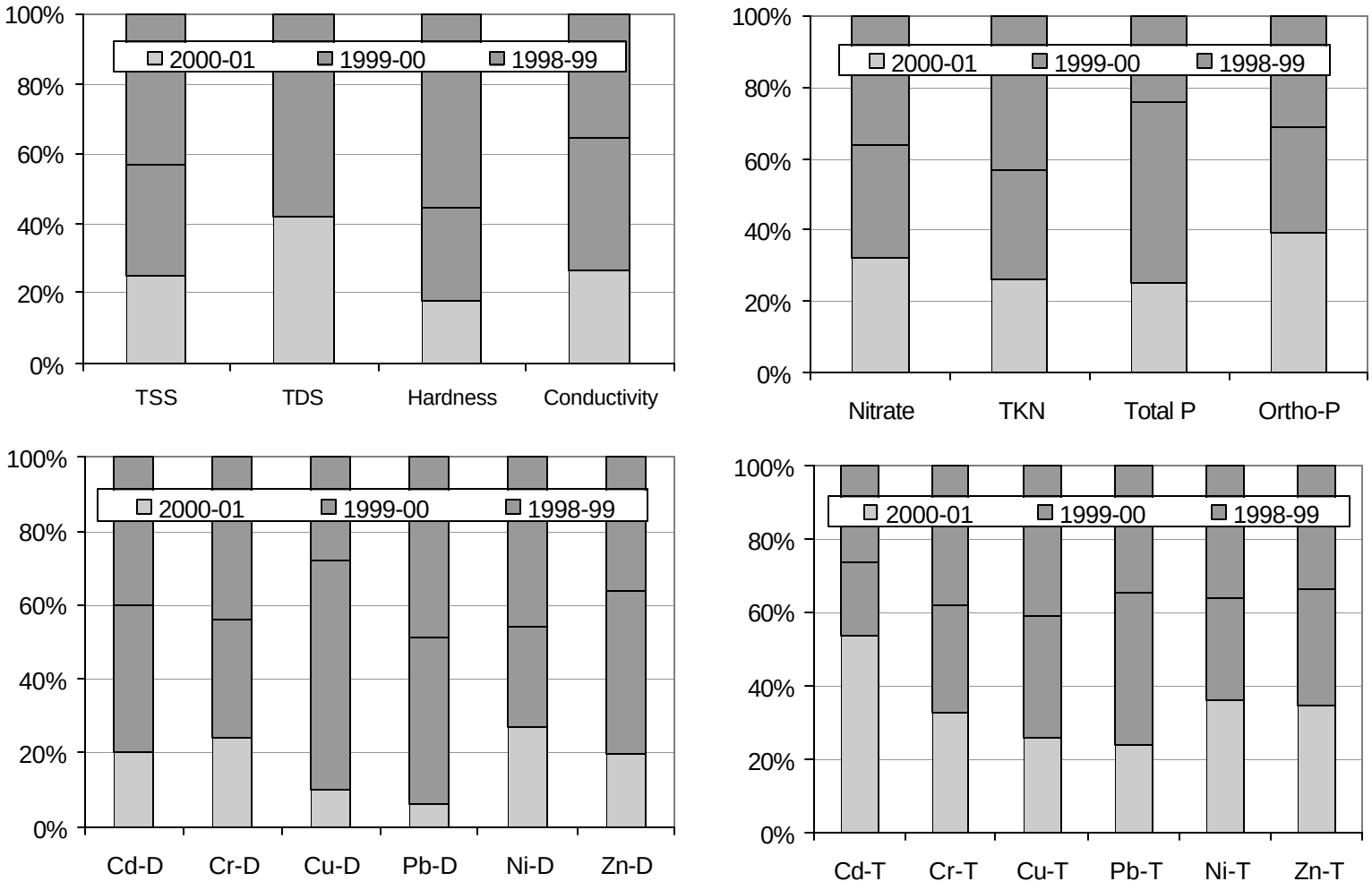

FIGURE 8 Caltrans statewide highways stormwater runoff quality compared to previous monitoring data

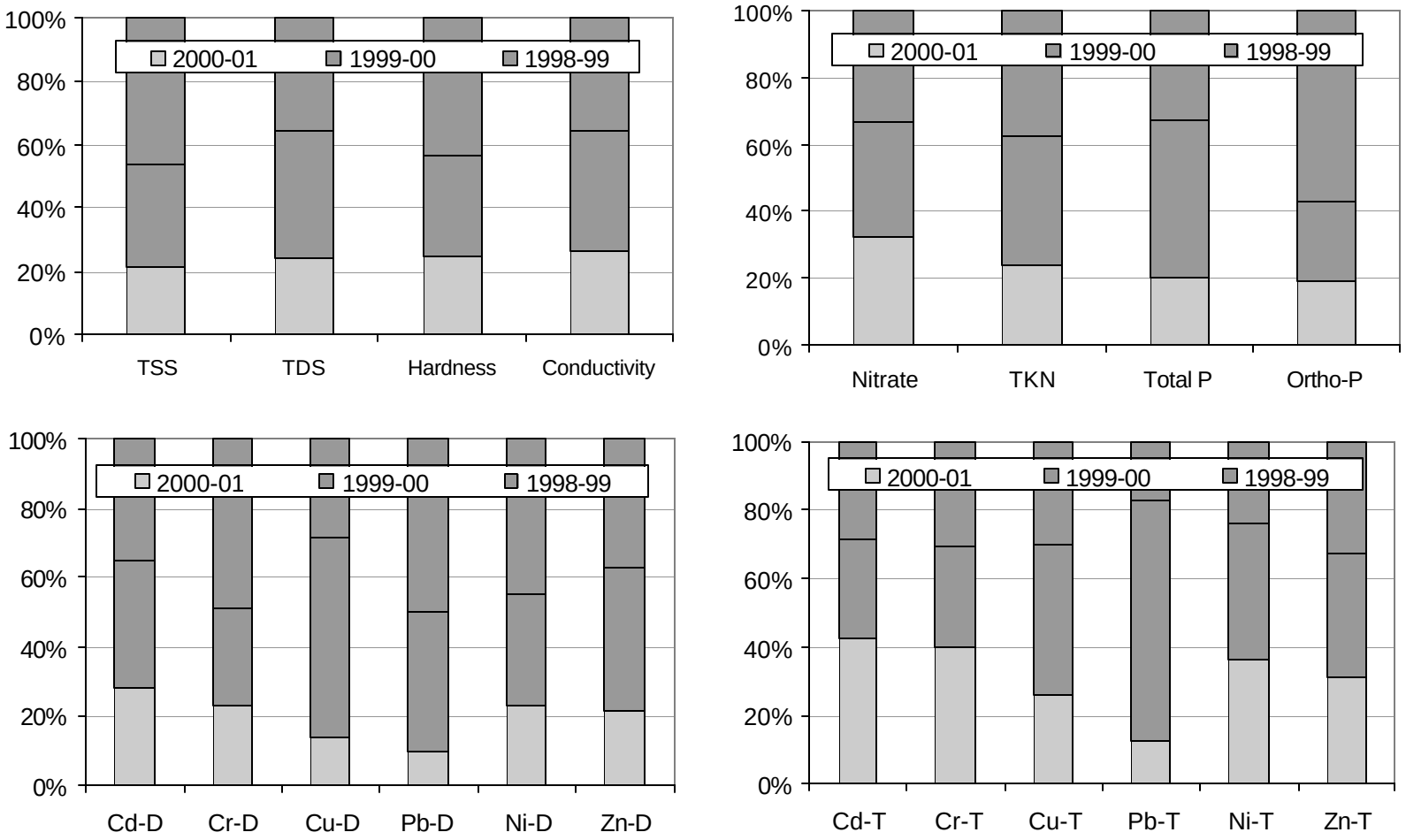

FIGURE 9 Caltrans statewide maintenance facilities stormwater runoff quality compared to previous monitoring data

TABLE 1 Number of Storm Events Monitored for each Caltrans Facility

Facility Type	Caltrans District	Number of sites monitored	Storm events monitored
Highways	1,2,3,4,5,6,8,9,10,11	31	192
Maintenance Station	1,3,4,12	4	27
Park and Rides	3,4,7,8,10,12	8	57
Rest Areas	2,5,6	3	22
Accelerations/Decelerations	8,11	4	25
TOTAL		**50**	**323**

TABLE 2 Statistical Summary of Caltrans Statewide Stormwater Runoff Quality During 2000-01 Monitoring Season

Parameter	Reporting Limit	Unit	Highways					Park and Rides					Maintenance Stations				
			Min	Max	Mean	Median	CV	Min	Max	Mean	Median	CV	Min	Max	Mean	Median	CV
Conventionals																	
pH	± 0.1	pH units	5.1	10.1	7.2	7.2	0.1	5.1	8.3	7.1	7.2	0.1	5.3	8.5	7.0	6.9	0.1
Conductivity	± 1.0	µmhos/cm	7.0	1285	95.8	65	1.3	5.7	296	58.9	36.5	1.0	5	157	46.4	36	0.8
TSS	1.0	mg/L	2.0	1373	94.4	55	1.8	7.0	216	45.8	29.5	1.0	6	220	54.3	34	1.1
TDS	1.0	mg/L	5.0	724	84.8	57	1.1	4.0	268	56.2	37.5	1.0	4	140	40.9	34	0.8
Hardness	1.0	mg/L	3.0	400	36.8	26	1.1	4.0	420	30.6	18	2.1	2	65	19.3	19	0.8
DOC	1.0	mg/L	1.3	155	14.7	9.8	1.2	1.0	68	14.6	9.4	1.0	2.1	69	11.7	6.8	1.3
TOC	1.0	mg/L	1.4	137	17.7	13	1.0	1.8	71	18.3	13	0.9	1.7	72	13.5	8.5	1.2
Nutrients																	
Nitrate as N	0.1	mg/L	0.1	48	1.2	NA	3.5	0.1	4.8	0.8	NA	1.4	0.2	2.8	0.7	NA	1.1
TKN	0.1	mg/L	0.1	14.5	1.8	1.4	1.0	0.2	9.3	2.1	1.7	0.8	0.1	2.9	1.1	0.8	0.7
Total Phosphorus	0.03	mg/L	0.03	4.7	0.3	NA	1.8	0.04	3.3	0.4	NA	1.8	0.03	1.04	0.2	NA	1.3
Orthophosphate	0.03	mg/L	0.04	2.3	0.2	NA	1.3	0.04	1.0	0.2	NA	1.1	0.04	0.9	0.1	0.1	1.6
Total Metals																	
Arsenic	1.0	ug/L	0.5	8.6	1.4	NA	0.9	0.5	3.6	1.1	0.9	0.7	0.6	82	5.6	2.8	3.7
Cadmium	0.2	ug/L	0.2	5.0	0.7	NA	0.9	0.2	3.6	0.5	0.4	1.2	0.2	3	0.6	NA	1.0
Chromium	1.0	ug/L	1.0	98	7.8	5.0	1.6	1.1	14.3	2.9	2	0.9	1.0	23.3	5.7	4.1	0.9
Copper	1.0	ug/L	1.2	230	22.3	16.8	1.2	2.3	51	13.5	10.4	0.8	3.5	25	11.4	8.8	0.6
Lead	1.0	ug/L	1.0	327	21.9	6.1	2.0	1.1	37	6.4	2.9	1.3	1.5	49	8.8	6.0	1.2
Nickel	2.0	ug/L	2.0	208	10.9	6.9	1.8	2.5	21	5.6	4.8	0.7	2.1	18.2	5.5	3.8	0.8
Zinc	5.0	ug/L	7.5	1245	129.8	81	1.3	18	787	107.8	71.5	1.1	26	381	105	84.0	0.8
Dissolved Metals																	
Arsenic	1.0	ug/L	0.6	4.8	0.9	0.8	0.7	0.5	2.7	0.7	0.6	0.8	0.9	81	5.0	1.9	4.1
Cadmium	0.2	ug/L	0.2	4.7	0.4	0.4	0.9	0.2	2.3	NA	NA	NA	0.3	2	0.5	0.4	0.8
Chromium	1.0	ug/L	1.0	19	2.6	1.5	1.2	1.1	2.3	NA	NA	NA	1.1	6	1.6	1.4	0.9
Copper	1.0	ug/L	1.1	121	11.4	8.5	1.1	1.1	51	8.9	6.2	1.0	2.9	18	7.9	6.3	0.6
Lead	1.0	ug/L	1.0	143	3.2	1.1	4.0	1.1	6	NA	NA	NA	1	23	NA	NA	NA
Nickel	2.0	ug/L	1.1	52	4.4	2.9	1.3	2.0	18	3.3	2.3	1.1	2.3	11	3.1	2.3	0.9
Zinc	5.0	ug/L	3.0	1017	59.4	28.0	2.0	3.7	485	61.9	31.5	1.4	16	376	74.2	49	1.0

TABLE 2 Statistical Summary of Caltrans Statewide Stormwater Runoff Quality During 2000-01 Monitoring Season (Continued)

Parameter	Reporting Limit	Unit	Rest Areas					Accelerations					Decelerations				
			Min	Max	Mean	Median	CV	Min	Max	Mean	Median	CV	Min	Max	Mean	Median	CV
Conventionals																	
pH	± 0.1	pH units	5.7	7.6	6.9	6.9	0.07	6.2	8.7	7.7	7.7	0.1	7	8.2	7.6	7.6	0.1
Conductivity	± 1.0	µmhos/cm	15.0	197	60.4	49.0	0.7	43.0	272	103.4	85.5	0.6	63	290	120.9	109	0.6
TSS	1.0	mg/L	7.0	247	61.7	39.0	0.9	45.0	400	123.1	101.5	0.8	19	366	64.9	43	1.7
TDS	1.0	mg/L	4.0	80	39.9	34.0	0.6	16.0	184	97.6	97	0.5	24	244	89.5	92	0.7
Hardness	1.0	mg/L	3.0	34	18.1	16.0	0.5	23.0	55	38.9	40	0.3	23	86	43.3	42	0.4
DOC	1.0	mg/L	2.1	37	12.4	10.9	0.8	4.6	25	14.2	14	0.4	4.9	39	15.9	15	0.6
TOC	1.0	mg/L	2.5	42	15.5	13.1	0.7	6.0	34	17.9	18	0.4	6.2	42	21.5	21.1	0.5
Nutrients																	
Nitrate as N	0.1	mg/L	0.2	3.4	0.9	NA	0.9	0.1	1.7	0.8	0.8	0.5	0.1	4.2	0.9	0.6	1.3
TKN	0.01	mg/L	0.2	6.5	2.7	2.5	0.7	1.2	4.0	1.9	1.6	0.4	0.4	7.7	1.8	1.6	1.1
Total Phosphorus	0.03	mg/L	0.1	1.4	0.4	0.3	0.8	0.1	0.5	0.3	0.3	0.4	0.1	0.3	0.2	0.2	0.4
Orthophosphate	0.03	mg/L	0.03	0.6	0.2	NA	0.8	0.06	0.3	0.2	NA	0.5	0.04	0.2	0.1	NA	0.5
Total Metals																	
Arsenic	1.0	ug/L	1.0	7.8	1.9	1.1	1.0	1.1	2.2	1.3	1.2	0.4	1.2	5.4	1.2	0.8	1.3
Cadmium	0.2	ug/L	0.2	0.6	0.3	NA	0.5	0.4	1.1	0.6	NA	0.4	0.3	2.5	0.6	NA	1.0
Chromium	1.0	ug/L	1.3	18.0	4.2	2.8	1.0	1.2	13	5.7	5.0	0.6	1.2	20	5.6	3.5	1.0
Copper	1.0	ug/L	4.6	44.0	13.1	11.0	0.8	4.7	57	22	18	0.6	6.3	113	22.1	14	1.5
Lead	1.0	ug/L	1.1	29.0	6.4	3.5	1.2	3.4	199	52.2	34.5	1.1	3.8	135	21.7	7.2	1.8
Nickel	2.0	ug/L	1.8	33.0	6.9	3.4	1.3	2.0	15	5.4	4.3	0.7	2	33	5.8	3.4	1.7
Zinc	5.0	ug/L	21	374	101.9	78	0.8	49	439	165.1	133	0.7	20	1680	199.9	85	2.8
Dissolved Metals																	
Arsenic	1.0	ug/L	1.0	6.1	1.6	NA	1.0	1.1	1.5	NA	NA	NA	0.3	3	0.7	NA	1.1
Cadmium	0.2	ug/L	0.2	0.2	NA	NA	NA	0.3	0.5	NA	NA	NA	0.2	0.9	0.4	NA	0.2
Chromium	1.0	ug/L	1.0	6.0	1.5	NA	1.0	1.2	4.2	2.4	2.6	0.4	1.3	8.1	3.2	2.1	0.8
Copper	1.0	ug/L	2.7	22.0	7.8	5.4	0.7	2.7	26	10.4	9.3	0.6	4.0	56	12.4	8.4	1.2
Lead	1.0	ug/L	1.0	2.5	1.1	NA	0.5	1.9	35	9.6	4.4	1.3	1.1	8.2	2.1	1.1	1.2
Nickel	2.0	ug/L	2.0	5.1	2.6	2.0	0.5	2.0	7.3	3.1	2.6	0.5	2.1	22	3.5	2.1	1.9
Zinc	5.0	ug/L	14	160	52.7	42	0.7	9.5	209	55.5	36.5	1.1	8.9	8.5	107.8	37	2.5

CV = coefficient of variation.

NA = not available, statistics are not calculated for data sets with a high number of non-detects.

TABLE 3 Summary of Caltrans Statewide Highway Stormwater Runoff Characteristics Compared to Historical Data

Parameter	Reporting Limit	Unit	Statewide Monitoring (2000-01)					Previous Monitoring (1997-00)				
			Min	Max	Mean	Median	CV	Min	Max	Mean	Median	CV
Conventionals												
pH	± 0.1	pH units	5.1	10.1	7.2	7.2	0.1	6.2	9.6	7.5	7.4	0.06
Conductivity	± 1.0	µmhos/cm	7.0	1285	95.8	65	1.3	4	2700	163.3	104	1.6
TSS	1.0	mg/L	2.0	1373	94.4	55	1.8	3	29000	276.4	77	5.12
TDS	1.0	mg/L	5.0	724	84.8	57	1.1	14	3200	226.7	160	1.4
Hardness	1.0	mg/L	3.0	400	36.8	26	1.1	5	1000	62.8	45.3	1.4
DOC	1.0	mg/L	1.3	155	14.7	9.8	1.2	NA	NA	NA	NA	NA
TOC	1.0	mg/L	1.4	137	17.7	13	1.0	0.6	350.1	14.6	10.6	1.4
Nutrients												
Nitrate as N	0.1	mg/L	0.1	48	1.2	NA	3.5	0.03	9.5	1.2	0.8	1.0
TKN	0.1	mg/L	0.1	14.5	1.8	1.4	1.0	0.08	57	3.0	1.7	1.6
Total Phosphorus	0.03	mg/L	0.03	4.7	0.3	NA	1.8	0.01	37.5	0.8	0.2	3.4
Orthophosphate	0.03	mg/L	0.04	2.3	0.2	NA	1.3	0.01	6	0.5	0.2	1.9
Total Metals												
Arsenic	1.0	ug/L	0.5	8.6	1.4	NA	0.9	0.2	2300	26.6	0.6	8.9
Cadmium	0.2	ug/L	0.2	5.0	0.7	NA	0.9	0.1	24	1.3	0.8	1.3
Chromium	1.0	ug/L	1.0	98	7.8	5.0	1.6	0.5	1800	17.2	7.5	5.1
Copper	1.0	ug/L	1.2	230	22.3	16.8	1.2	0.2	9500	63.8	26.6	6.0
Lead	1.0	ug/L	1.0	327	21.9	6.1	2.0	0.1	2300	107.6	33.7	1.9
Nickel	2.0	ug/L	2.0	208	10.9	6.9	1.8	0.4	1500	16.4	7.1	4.3
Zinc	5.0	ug/L	7.5	1245	129.8	81	1.3	2.5	4800	258.9	142.6	1.6
Dissolved Metals												
Arsenic	1.0	ug/L	0.6	4.8	0.9	0.8	0.7	0.4	10	1.8	1.2	1.1
Cadmium	0.2	ug/L	0.2	4.7	0.4	0.4	0.9	0.02	6.1	0.2	0.2	1.6
Chromium	1.0	ug/L	1.0	19	2.6	1.5	1.2	0.7	22	2.3	1.9	0.8
Copper	1.0	ug/L	1.1	121	11.4	8.5	1.1	1.1	88	13.2	9.9	0.8
Lead	1.0	ug/L	1.0	143	3.2	1.1	4.0	0.2	160	4.8	1.9	2.3
Nickel	2.0	ug/L	1.1	52	4.4	2.9	1.3	0.5	36	3.3	2.2	1.2
Zinc	5.0	ug/L	3.0	1017	59.4	28.0	2.0	5.1	870	63.8	42	1.2

CV = coefficient of variation.
NA = not available, no DOC analysis were performed during 1997-00 monitoring years.